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IMPACT OF CATHODE SLOT ON CURRENT DISTRIBUTION IN CATHODE CARBON OF AN ALUMINUM ELECTROLYTICl CELL

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The current distribution in a fresh aluminum electrolytic cell with slotted carbons is investigated by the Finite Element Method (FEM). The effects of the length of slots, l_a and l_c on current distribution were also determined. The maximum local current density and its position do not change with an increase in l_c ($0 \leq l_c \leq 200$ mm) for a 400 mm slot located 150 mm from the upper surface of the cathode carbon. However, the maximum current density shifts towards the cell center with increasing slot lengths. Current distribution control thus plays a role in optimizing the cathode slot length.

Keywords: aluminum, electrolytic cell, slotted cathode carbon, current distribution, FEM

INTRODUCTION

Aluminum, which is usually manufactured by the Hall-Héroult method, is used to prepare electrolytic cells. A typical cell (popularly known as a pot) has anodes, an electrolyte, molten aluminum, cathode carbons, and other lining materials. The electric current is vertically supplied into the cell through an anode bar, and flows horizontally out of the cell through cathode collectors. The cathode collectors are horizontal steel bars integrated to the lower part of the cathode, and sequentially connect to the next cell. The current inherently flows via the least resistance path in conductors, and the maximum concentration of the current passes via the exterior of the cathode carbon. This process is illustrated in Figure 1.

This current flow poses two adverse effects on cells. First, fluctuations occur in the molten aluminum pad due to the interaction of the horizontal current (HC) of molten aluminum with the vertical magnetic field [1].

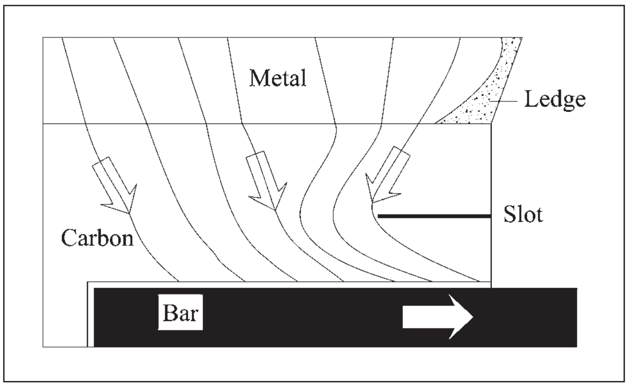

Figure 1 Schematic representation of current path in a conventional cathode

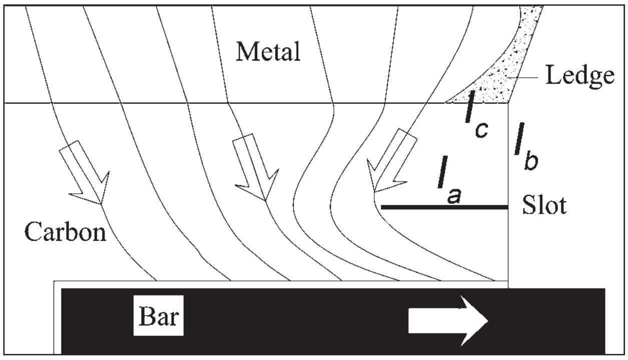

Figure 2 Schematic representation of current path in a slotted cathode

This fluctuation limits the possibility of space minimization between the anode (anode carbon block) and the cathode (molten aluminum), i.e., the anode-cathode distance (ACD), and increases the risk of short circuits and re-oxidation of aluminum. The other negative effect involves the uneven cathode current distribution along the longitudinal direction of the cathode block. Cathode wear, which usually occurs from physical scratched, chemical elimination and electrochemical corrosion [2-3], will be intensified by the uneven current distribution. It is widely accepted that such an uneven current distribution in the cathode will lead to a "W"-shape wear of carbon cathode block.

The horizontal current can be decreased by changing the cathode layout. Numerous studies have been conducted on modifying the layout of the cathode structure, such as collector bars [4-7], cathode carbons [8-9], paste between the cathode carbon and the collector bar [10], and so on. In a recent work [11], a kind of cathode layout with a slotted cathode carbon block was proposed. This model is illustrated in Figure 2. The slots in the cathode

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carbon block are filled with insulating materials. The main advantage of using a slotted cathode carbon is that it helps decrease the horizontal current. The slotted cathode carbon block favorably influences the distribution of current in the block. Hence, this work aims at analyzing the impacts of slotted cathodes on the distribution of current in the cathode carbon block. The effects of slot length (l_a) and the ledge toe length (l_c, shown in Figure 2) on the current distribution are studied.

MODEL DESCRIPTION

As the cell operation in commercial cells is coupled with complex electric fields, the following hypotheses are applied in order to simplify the calculation.

- A new cathode carbon (without wear) is used in the cell
- The ACD and anodic current density are constant in the cell
- There are no bubbles in the electrolyte
- There is no sludge at the bottom of the cell
- The material filled in the slot is completely electrically insulating
- The cell keeps a consistent-state situation.

The monitoring equations for the current distribution in the cell are the charge conservation equation and Ohm's law, as expressed in Eqs. (1) and (2), respectively.

Charge conservation equation:

$$\nabla \cdot \vec{J} = 0 \quad (1)$$

Ohm's law:

$$\vec{J} = \sigma \vec{E} \quad (2)$$

where $\vec{J}$ is the conductor current density, σ is the conductivity, and $\vec{E}$ represents the electric field intensity.

Figure 3 shows the framework of an aluminum electrolytic cell with slotted cathodes. The electric field of a conventional cell is simulated and illustrated in Figure 3 for comparison.

The technical parameters are listed in Table 1. The slot is located at a distance of 150 mm from the top facade of the carbon block (l_b in Figure 2).

ANSYS software for finite element analysis was used for electrical measurements. The end edge of the collector bar was set zero electric potential. A steady electric current was applied on the upper surface of the anode carbon. The core and base of the cell were considered as the starting points for this study. The x-axis, y-axis, and z-axis are represented by the length, height and short side of the cell slice, respectively.

Table 1 **Technological parameters of an electrolytic reduction cell**

Parameter	Value
Current	300 kA
Number of carbon block	26
Number of collector bar	104
Metal level	200 mm
Electrolyte level	190 mm
Cathode carbon block ($L \times W \times H$)	3 450 × 515 × 450 mm
Collector bar ($L \times W \times H$)	2 000 × 65 × 180 mm

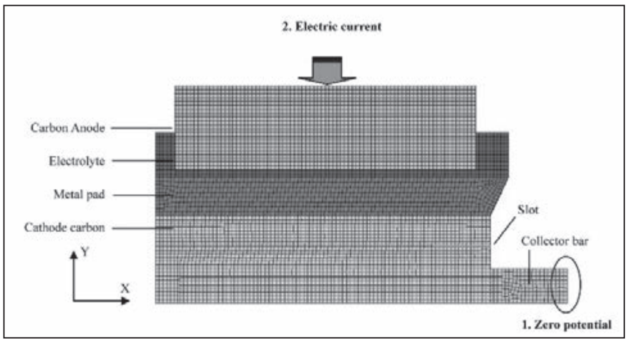

Figure 3 The model of the aluminum electrolytic cell with slotted cathode carbon

RESULTS AND DISCUSSION

In a conventional cell, current flows into the cathode floor from molten aluminum with a higher current density at the floor border regions (cell side) than at the floor central regions (cell center), as illustrated in Figure 4a.

However, in the new cell model where the slots are filled with insulating materials, the increase in resistance near the cell side allows for more current to flow through the central region as compared with that in the conventional cell. Then, the effects of different ledge toe lengths, l_c (0 mm, 100 mm and 200 mm) on the current distribution at the exterior surface of the cathode were investigated, the slot length (l_a in Figure 2) was 400 mm.

Figure 5 correlates the current distribution at the facade of the cathode carbon block with different values of lengths of l_c.

Because of its high electrical resistance, the ledge is believed to act as an insulator for numerical modeling studies. Hence, an increase in l_c would decrease the effective conductive area between the molten aluminum and the cathode carbon. The current gathers around the

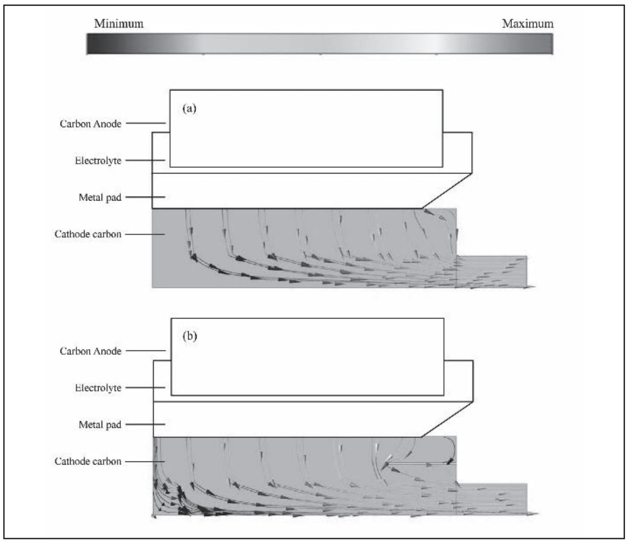

Figure 4 The electric current streamline in cathode carbon and collector bar. (a) conventional cathode structure (b) novel cathode with a slotted cathode carbon block

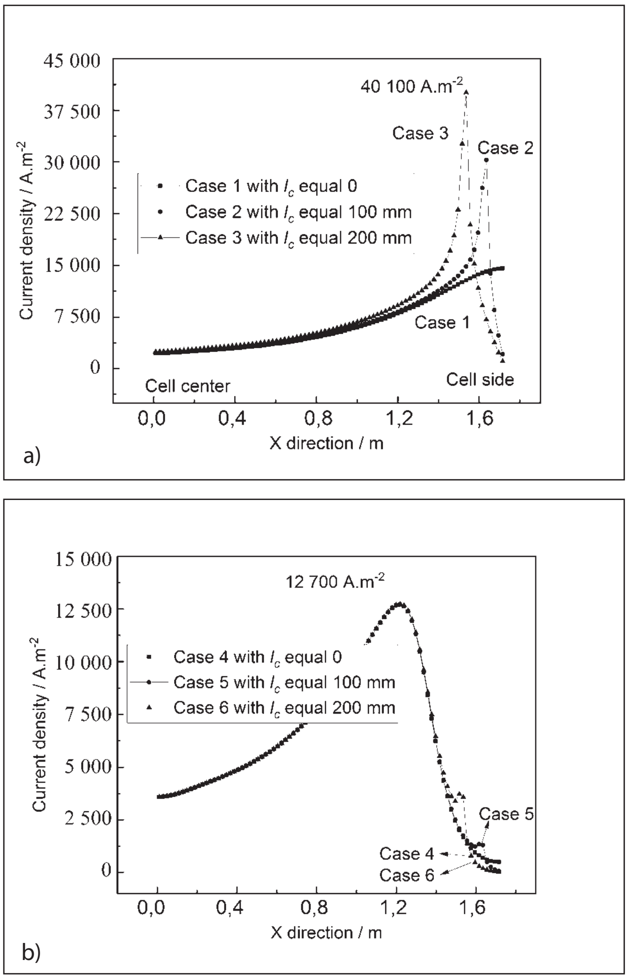

Figure 5 Current distribution at the surface of the cathode carbon block with different length of ledge toe (l_c)
(a) conventional cathode structure
(b) novel cathode with a slotted cathode carbon block

ledge toe, and the maximum current density escalates rapidly when moving toward the cell center, as shown in Figure 5a. This finding agrees well with the results from other literature reviews [12].

However, the current distribution at the exterior of the novel cathode model is quite different from the of the conventional one: (a) a minor variation in the current distribution is seen with an increase in l_c, and the maximum current density is observed at a distance of almost 1,2 m from the cell center for the 400 mm slot, as highlighted in Figure 5b; (b) the maximum current density decreases remarkably from 40 100 A·m^{-2} to 12 700 A·m^{-2} for a 400 mm slot. In accordance with the correlation between the current density (i/A·m^{-2}) and the wear rate (W/m·year^{-1}) [13], as displayed in Eq. 3, the wear rate would decrease from 51,0 mm (40 100 A·m^{-2}) to 33,7 mm (12 700 A·m^{-2}). The introduction of slots in the cathodes will significantly prolong the cell life.

$$W = 0{,}015 \ln(i) - 0{,}108 \qquad (3)$$

The effects of l_a values of 200 mm, 300 mm, and 400 mm on the current distribution at the exterior of the cathode carbon were investigated.

Figure 6 shows the current distribution at the exterior of the cathode carbon block with different slot

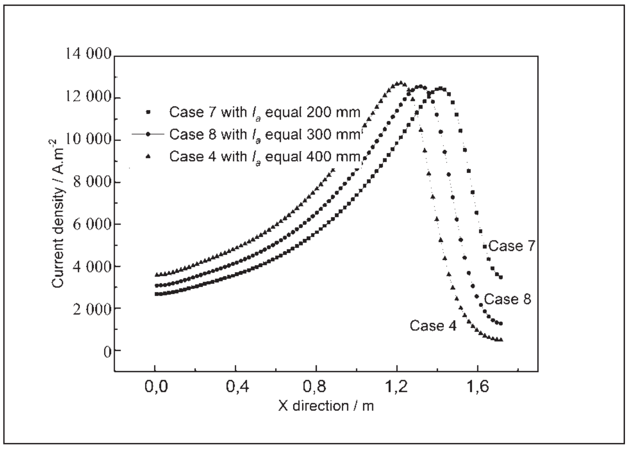

Figure 6 Current distribution at the surface of the cathode carbon block with different lengths of slot for a 0 mm ledge toe

lengths for the 0 mm ledge toe. It can be seen that there is negligible influence of the slot length on the maximum current density. However, the peak position of the current density moves from the side part of the cell toward the central regions with increasing slot length.

Generally, the ledge shape is dependent on the cell heat balance, which is very difficult to control. Thus, the current distribution at the facade of the cathode carbon changes from case to case. The aforementioned findings suggest that the slotted cathode carbon would play an important role in the distribution of cathode current. It can be inferred that the current distribution at the exterior of the cathode carbon block can be controlled through optimization of the slot position and length in cathode carbons. Further investigations are required to fully understand the effects of slotted cathode on current distribution in the cell.

CONCLUSIONS

Cathode wear in an aluminum electrolytic cell is directly associated with the current distribution at the exterior of the cathode carbon block. Moreover, there is a rapid increase in the maximum current density when its location moves toward the cell center as the length of the ledge toe increases. However, in the slotted cathode carbon cell, the highest local current density and its position do not change with the increase in l_c ($0 \le l_c \le 200$ mm) for a 400 mm slot placed 150 mm away from the upper surface of the cathode carbon. There is a shift in the position of the maximum current density toward the cell center with increasing slot lengths. Controlling the current distribution would be instrumental in optimizing the slot in cathode carbons.

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